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NOTES ON STANDARD WAVE LENGTHS SPECTROGRAPHS, AND SPECTRUM TUBES

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NOTES ON STANDARD WAVE LENGTHS, SPECTROGRAPHS, AND SPECTRUM TUBES

By W. F. Meggers and Keivin Burns

ABSTRACT

I. Standard Wave Lengths in the Cadmium Spectrum.—The wave lengths for 13 lines in the spectrum of tubes containing cadmium vapor at low pressure are measured relative to the primary standard by means of the Fabry and Perot étalon interferometer. The probable error in most of these values is less than 0.001 A. Constant frequency differences are established which define the separation of subordinate series limits. Evidence that the wave lengths derived from spectrum tubes are reproducible is presented.

II. A Quartz Rock Salt Spectrograph.—An instrument whose optical parts consist of quartz and rock salt is described. This spectrograph was designed for photography of interference phenomena in the ultra-violet, but is also serviceable in the visible spectrum and has certain advantages over other types of spectrographs for investigating the shorter waves.

III. A Stigmatic Concave Grating Mounting.—The Wadsworth mounting in which the slit is, in effect, placed at infinity with the aid of an auxiliary mirror, thus filling the concave grating with parallel light, gives spectral images which are practically free from astigmatism. The characteristics and performance of such an instrument are outlined, and detailed drawings of the apparatus are reproduced.

IV. The Preparation of Spectrum Tubes.—Instructions and suggestions are given for the preparation of Plücker tubes commonly required for optical demonstration, testing, or research. The remarks apply especially to tubes containing hydrogen, nitrogen, oxygen, helium, neon, and argon.

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I. STANDARD WAVE LENGTHS IN THE CADMIUM SPECTRUM

In the course of determinations of secondary standards in the spectra of the inert gases[1] the wave lengths were measured relative to that of the red radiation from cadmium, and a very large number of photographic exposures showing interference fringes of cadmium lines between 6438 an 2980 A were thus obtained. The spectrograph described in Part II of these notes was employed in making these exposures. Four different sets of interferometer plates and a series of invar separators ranging from 2 to 40 mm were used in these experiments, many of the lines being observed from 40 to 50 times on various combinations of plates and separators. These observations are collected in Table 1 as additional secondary standards of wave length.

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[1] Helium, B. S. Bull., **14**, p. 159; 1917. Neon, B. S. Bull., **14**, p. 765; 1918. Argon, Krypton, and Xenon, B. S. Sci. Papers, **17**, p. 193; 1921.

TABLE 1.—Wave Lengths in the Spectrum of Cadmium

Wave lengths (B. S. adopted), I. A.	Values as measured by various interferometers								
	F. and B. nickel quartz	Weight	Copper glass	Weight	Thin nickel quartz	Weight	Nickel fused quartz	Weight	Michelson[a]
2980.6216.......	6216	3	....	....	....	....	....	....	....
3080.827.......	827	1	....	....	....	....	....	....	....
3133.167.......	167	1	....	....	....	....	....	....	....
3252.5248.......	5248	7	....	....	....	....	....	....	....
3403.6529.......	6526	11	....	....	....	....	6547	2	....
3466.2010.......	2002	8	....	....	2030	4	2007	10	....
3467.6559.......	6557	4	....	....	6553	1	6564	2	....
3610.5098.......	5098	9	5094	10	5109	7	5095	10	....
3612.8748.......	8743	6	....	....	8764	6	8742	10	....
4662.3525.......	3530	7	3521	8	....	....	3524	10	....
4678.1504.......	1502	8	1503	12	1507	11	1505	10	....
4799.9139.......	9141	6	9137	3	9121	4	9143	10	9088
5085.8230.......	8236	9	8237	12	8217	10	8229	10	8219
6438.4696.......	4696	....	4696	....	4696	....	4696	....	4696

[a] Michelson, Trav. et Mem., **11**, p. 85; 1895. The original values, 4799.9107, 5085.8240, and 6438.4722. have been reduced to the International system which defines the wave length of the red radiation at 15° C and 760 mm as 6438.4696 Angstrom units.

The apparatus and method of wave length comparison have been described in the publications referred to above, and it is necessary to add only a few more words in explanation of Table 1. Columns 2, 3, 4, and 5 contain the mean results from different sets of interferometers, the "F. and B. nickel-quartz" referring to the identical nickeled quartz plates used by Fabry and Buisson[2] in their measurements of secondary standards in the spectrum of the iron arc. These were also used by Burns for the same purpose,[3] and again by Burns, Meggers, and Merrill[4] for measurements of wave lengths in the spectrum of neon.

H-shaped cadmium tubes, viewed end on, were used throughout, and tubes of quartz permitted observations on wave lengths shorter than 3400 A appearing in column 2. The shorter lines were not observed in the other series of comparisons on account of the absorption of glass either in the tubes or in the interferometer plates.

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[2] Astrophys. J., **28**, p. 169; 1908.

[3] B. S. Bull., **12**, p. 179; 5191.

[4] B. S. Bull., **14**, p. 765; 1918.

The weight assigned to each value is based upon the number of observations with relatively large orders of interference and is therefore indicative of the probable relative accuracy. From the concordance among different sets of observations on the well-determined lines it appears that the probable errors in these are less than 0.001 A, although our value for 4799 exceeds Michelson's by 0.005 A.

The relative accuracy of some of the values in Table 1 may be tested if the frequency differences of corresponding pairs of lines in the subordinate series are assumed to be constant. For this purpose Table 2, giving the frequency in vacuum and the series notation for each line, has been prepared.

TABLE 2.—Cadmium Wave Lengths and Frequencies in Vacuum

λ(air)	λ(vac.)	ν(vac.)	Notation.	λ(air)	λ(vac.)	ν(vac.)	Notation
2980. 6216	2981. 4889	33540. 289	$2p_1-4d$	3610. 5098	3611. 5358	27689. 051	$2p_1-3d$
3080. 827	3081. 719	32449. 422	$2p_3-2s$	3612. 8748	3613. 9014	27670. 926	$2p_1-3d'$
3133. 167	3134. 072	31907. 371	$2p_2-2s$	4662. 3525	4663. 6535	21442. 416	$2P-4D$
3252. 5248	3253. 4597	30736. 511	$2p_1-2s$	4678. 1504	4679. 4556	21370. 007	$2p_3-1s$
3403. 6529	3404. 6260	29371. 802	$2p_3-3d''$	4799. 9139	4801. 2514	20827. 903	$2p_2-1s$
3466. 2010	3467. 1900	28841. 800	$2p_2-3d'$	5085. 8230	5087. 2365	19657. 038	$2p_1-1s$
3467. 6559	3468. 6453	28829. 699	$2p_2-3d''$	6438. 4696	6440. 2454	15527. 359	$2P-3D$

From this table the following differences are obtained:

$$(2p_1-1s)-(2p_2-1s)=1170.865;$$
$$(2p_2-1s)-(2p_3-1s)=\ 542.104;$$
$$(2p_1-2s)-(2p_2-2s)=1170.860;$$
$$(2p_2-2s)-(2p_3-2s)=542.051;$$
$$(2p_2-3d')-(2p_1-3d')=1170.874;$$
$$(2p_3-3d'')-(2p_2-3d'')=542.103.$$

The value 542.051 is based upon a single observation of 3080.827 with a 7.5 mm étalon, which may be in error by two parts in a million, thus accounting for its deviation from the more reliable value 542.104. With this exception the frequency differences indicate that the relative errors in the wave lengths involved do not exceed one part in several millions. The limiting frequencies of both the sharp and diffuse triplet series of cadmium may therefore be said to show the following differences:

$$2p_1-2p_2=1170.866;$$
$$2p_2-2p_3=\ 542.104.$$

These results are rather surprising, in view of the fact that some of the cadmium lines are not strictly homogeneous, but consist of a strong component accompanied by close satellites. Michelson (loc. cit., 3. 143) examined the distribution of intensity in the red, green, and blue lines and found: 6438 a very narrow, symmetrical line whose half width = 0.0065 A; 5085 a close double, the intensity of whose components are in the ratio of 5 to 1, their distance apart = 0.022, and the half width of each = 0.0048 A; 4800 a triplet with two faint components of equal brightness and distant 0.10 A from the center. These results were confirmed by Fabry and Perot.[5]

In spite of the fact that some of the cadmium lines are known to be complex, their principal components, nevertheless, appear to be capable of very precise measurement, as is evidenced by the concordance in Table 1 and by the constancy of frequency differences from Table 2. Either the intensities of the fainter components are too low to influence the photographic image of the interference fringes due to the strong component, or their slight disturbing effect may be averaged out by the use of a variety of étalon sizes.

In this connection we wish to express our faith in the constancy and reproducibility of the wave lengths as emitted by a tube containing cadmium at low pressure. Since 1915, when one[6] of us pointed out the ease with which the separation of interferometer plates could be determined from observations on neon interferences, this laboratory has always photographed the neon spectrum along with that of cadmium. For the majority of these exposures the quartz tube containing neon as described (loc. cit., p. 202) was used, always under the same conditions. The radiations emitted by this neon tube have thus been compared with the red radiation from many different cadmium tubes because the latter are relatively short lived on account of the electrode sputtering and more frequent breakage of tubes operated in a furnace. The usual variations in operating conditions (temperature 250 to 320° C, current 20 to 200 ma, and pressure 0.005 mm Hg to perhaps several centimeters due principally to occluded gases in tubes not properly exhausted) showed no systematic displacements of cadmium lines relative to the adopted values of neon.

Furthermore, a special investigation was made to detect, if possible, any measurable variation in the neon wave lengths emitted by different tubes containing gas at different pressures. For this purpose special tubes were filled with neon gas at "high" and "low" pressures, the limits in pressure (about 0.1 mm Hg to several centimeters) being considerably outside the range (2 to 5 mm) found in ordinary tubes. The radiations from these "high" and "low" pressure neon tubes were carefully compared with the cadmium red radiation, the same cadmium tube being used under constant conditions for this series of experiments. No change as large as 1 part in 10 000 000, which is the probable error of observation, could be detected in the wave lengths derived from the fundamental standard.

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[5] Ann. de Chemie et de Phys., 7 series, **17**, p. 115; 1899.

[6] B. S. Bull., **12**, p. 203; 1915.

The mean of three series of comparisons made at the Bureau of Standards[7] on more than 20 neon wave lengths referred to cadmium show a maximum disagreement of 1 part in 16 000 000, and a similar comparison made by Meissner[8] shows practically the same close agreement with the mean of those made in our laboratory. In view of these facts, the wave lengths in both cadmium and neon sources may be considered to be reproducible in the same and in different laboratories well within the limiting precision attainable in wave length comparisons.

The wave lengths of the cadmium lines presented in Table 1 are therefore considered suitable secondary standards, leaving out of consideration, of course, the red line 6438.4696 A, which has the deserved distinction of being the primary standard for all measurements of wave lengths of light in international Angstrom units.

II. A QUARTZ ROCK SALT SPECTROGRAPH

This spectrograph was designed by Mr. E. D. Tillyer for the purpose of photographing interference rings,[9] particularly in the region from 2000 A to 3100 A. The dispersive element is a 60-degree rock salt prism. Achromatism and other corrections are effected by means of lenses of quartz and rock salt. By setting the photographic plate at an angle of 65 degrees to the axis of the camera, the region 2200 A to 3080 A is given in good definition. The maximum chromatic aberration is 0.8 mm or 0.1 per cent of the focal length, and the maximum field curvature is only slightly greater. The spectral lines are slightly broadened by astigmatism, a point in the slit giving an image drawn out at right angles to the length of the slit. The images of circular interference fringes therefore remain sharp and are susceptible of accurate measurement.

The instrument has been used very successfully in the spectral region for which it was designed. Furthermore, it has been found to perform satisfactorily when used to compare the spectra of the rare gases throughout the region 2600 A to 8000 A with the cadmium red line. For use in the visible spectrum the plate holder is set at an angle of about 50 degrees to the axis of the camera. With this setting the definition is fair throughout, yet the blue and green are not in perfect focus when the red (6438 A) and ultra-violet (3200 A) are both sharp.

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[7] B. S. Bull., 14, p. 765; 1918.

[8] Ann. d. Phys., 51, p. 115; 1916.

[9] B. S. Bull., 14, p. 710; 1918.

For wave length 2500 A the focal length of the collimator is 1000 mm, that of the camera is 800 mm. Both have 50 mm of clear aperture. Each lens has one element of right-handed and one of left-handed quartz of equal median thickness. The camera lens has no rock salt element. The plane plate in the collimator lens serves the double purpose of protecting the rock salt and counteracting the optical rotation of the other quartz element.

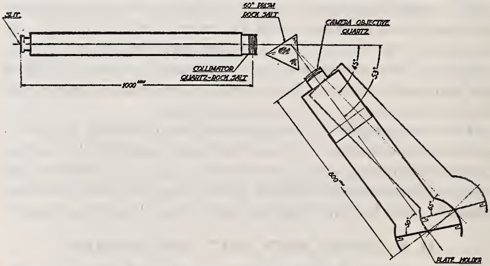

Fig. 1.—*Quartz rock salt spectrograph, showing optical system of quartz and rock salt*

Two positions of the camera are indicated, full line position for ultra-violet and dotted line position for visible spectrum

The radii and thicknesses of the lenses are as follows, beginning on the side toward the slit:

Collimator lens:

$$\left.\begin{array}{l} r_1=\infty;\ \text{plane}\\ r_2=\infty;\ \text{plane}\end{array}\right\}\text{right-handed quartz, thickness 6.5 mm.}$$

$$\left.\begin{array}{l} r_3=+2055\text{ mm; convex}\\ r_4=-544\text{ mm; concave}\end{array}\right\}\begin{array}{l}\text{rock salt, thickness at center 6.0 mm;}\\ \text{separation at center 0.5 mm.}\end{array}$$

$$\left.\begin{array}{l} r_5=+595\text{ mm; convex}\\ r_6=+684\text{ mm; convex}\end{array}\right\}\begin{array}{l}\text{left-handed quartz, thickness at center}\\ \text{7.0 mm.}\end{array}$$

Camera lens:

$$\left.\begin{array}{l} r_1 = +\ 931 \text{ mm; convex} \\ r_2 = -24200 \text{ mm; concave} \end{array}\right\} \begin{array}{l}\text{right-handed quartz, thickness at center 7.0 mm; separation at center} \\ \text{1.0 mm.}\end{array}$$

$$\left.\begin{array}{l} r_3 = +\ 506 \text{ mm; convex} \\ r_4 = -1058 \text{ mm; concave} \end{array}\right\} \begin{array}{l}\text{left-handed quartz, thickness at center} \\ \text{7.0 mm.}\end{array}$$

Fig. 1 shows the plan of the spectrograph. The camera may be rotated around the optical center of the lens. The distance between the camera lens and the plate is adjustable, and the plate holder may be rotated around a point on the axis of the camera lens.

The dispersion is about 1 A per millimeter at 2000 A, 3 A per millimeter at 2300 A, 5 A per millimeter at 2600 A, 10 A per millimeter at 3100 A, 22 A per millimeter at 3800 A, 45 A per millimeter at 4900 A, and 90 A per millimeter at 6000 A. Compared with a one-prism quartz spectrograph having lenses of the same aperture ratio, the instrument is about as rapid but has greater dispersion for the longer waves and has the advantage of a field which is nearly flat. For work with the shortest wave lengths it is necessary that the polish on the salt be excellent, the least cloudiness causing a large amount of scattering of the radiations of wave length less than 3000 A. In such an instrument it is advisable to have the quartz rock salt lens hermetically sealed and the prism protected by very thin quartz plates, although in the present case the rock salt prism surfaces have been preserved for several years by covering the prism, when not in use, with a glass jar containing phosphoric pentoxide.

III. A STIGMATIC CONCAVE GRATING MOUNTING

It was first pointed out by Wadsworth [10] that a stigmatic image is obtained with a concave grating if the slit is put at infinity and the spectra are observed near the normal to the grating. Runge and Paschen [11] used a lens with the slit at its focus filling the grating with parallel light. On account of absorption and faults of achromatism in lenses, Fabry and Buisson [12] recommended the use of a mirror with which to illuminate the grating. Such an arrangement was installed in a basement laboratory at this Bureau [13] in 1914 and has been in almost continuous use ever since. In view of the fact that this type of grating mounting has many excellent features but has never been described in detail, we have considered it worth while to show a plan of our instrument (Fig. 2), reproduce our working drawings of its parts (Figs. 3, 4, and 5), and add a few notes on its characteristics and performance.

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[10] Astrophys. J., 3, pp. 54–58; 1896.

[11] Ann. d. Phys., 61, p. 644; 1897.

[12] J. de Phys. (4), 9, p. 940; 1910.

[13] B. S. Bull., 14, p. 374; 1918.

The light from a source whose image is focussed on the slit S falls upon a concave mirror M (of speculum metal), which sends a parallel beam of light to the grating G. The slit and grating are so close together, as seen from the mirror, that the aberration due to the mirror is small and the grating spectra are focussed in the camera P without appreciable astigmatism. This is an advantage which permits the use of diaphragms in front of the slit for the photography of comparison spectra in juxtaposition and makes it possible to study the spectra of interferences or of localized parts of sources whose images are focussed on the slit. There are in reality two stigmatic foci, one for vertical lines

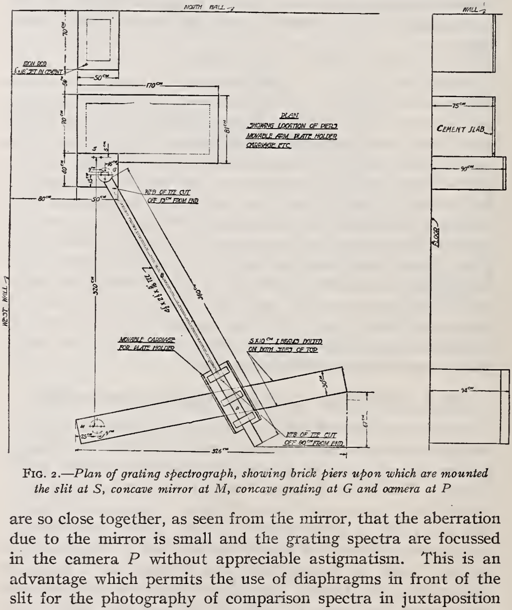

Fig. 2.—*Plan of grating spectrograph, showing brick piers upon which are mounted the slit at S, concave mirror at M, concave grating at G and camera at P*

and the other for horizontal lines. In the case of our instrument the former is used for obtaining the narrowest slit images, and the latter, which is about 2 mm farther from the grating, when sharpest definition along the length of the slit is required. The spectrum, which is nearly normal, is formed on the photographic plate *P*, which is parallel to the face of the grating and may be

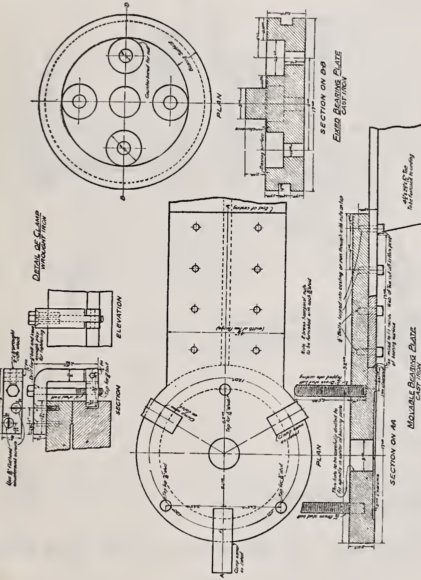

Fig. 3.—*Details of bearing plates and clamp for mounting the grating holder*

adjusted in its distance from *G* to put it in the focal plane. The grating and the camera are mounted on the steel beam *B*, which is pivoted on a vertical axis passing through the middle of the grating. To pass from one region of the spectrum to another the beam *B* is moved along the pier to definite positions, which are calibrated for spectral region and camera focus.

When the incident and diffracted beams make an angle i, the wave length λ at the middle of the plate is

$$\lambda = \frac{b \sin i}{n},$$

in which n represents the order number of the spectrum and b the grating space. The distance from the plate to the grating is

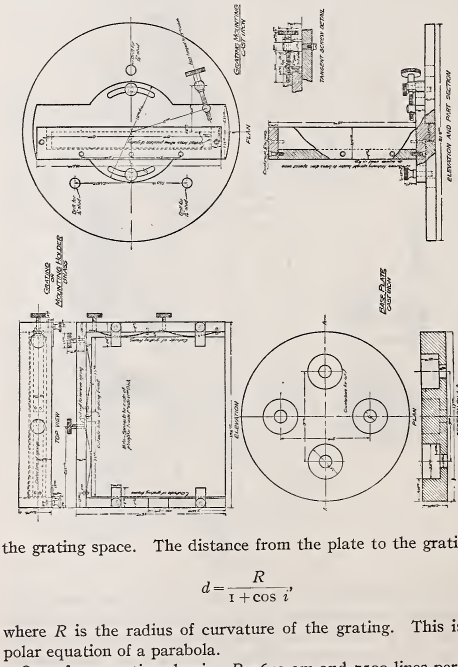
GRATING MOUNTING CAST IRON
PLAN
TANGENT SCREW DETAIL
ELEVATION AND PART SECTION
GRATING OR MOUNTING HOLDER BRASS
TOP VIEW
ELEVATION
BASE PLATE CAST IRON
PLAN
SECTION ON A-A
A
A

FIG. 4.—*Details of the grating holder*

$$d = \frac{R}{1 + \cos i},$$

where R is the radius of curvature of the grating. This is the polar equation of a parabola.

One of our gratings having $R = 640$ cm and 7500 lines per inch ($b = 0.0003387$ cm) permits the photography of spectra from

2000 A in the first order when $i=5$ degrees to about 6000 A in the fourth order when $i=45$ degrees. The distance of the plate from the grating increases from 320.8 cm in the first position to 374.9 cm in the last, so that the focal curve is not a circle, as in the case of a Rowland mounting. This produces a gradual increase in the dispersion with increasing wave length. At 3000 A 1 mm along the plate corresponds to 10.488 A, at 9000 A it is 10.306 A. Flat plates, 8 inches (20 cm) in length record an interval of 2000 A in the first

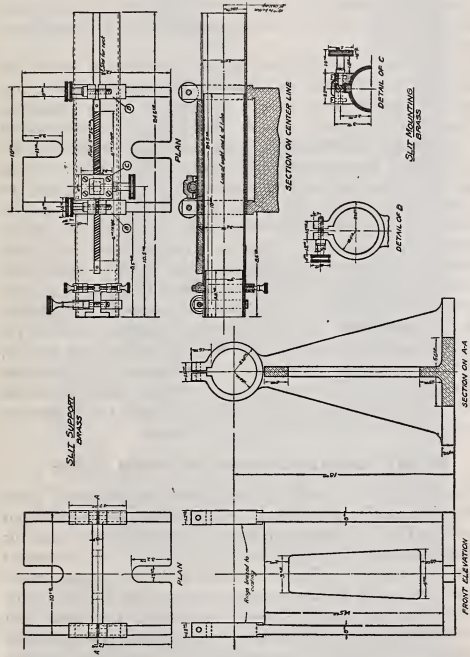

FIG. 5.—*Details of the slit support*

order spectrum, all of which is in satisfactory focus except the extreme ends. For wave length measurements relative to the secondary standards the deviation from a normal spectrum is easily corrected from a curve obtained by plotting the differences between the actual values of the standard lines and those computed from the measurements on the assumption that the spectrum is strictly normal.

In addition to the stigmatic feature of this type of concave grating mounting it has an advantage in occupying about one-fourth the space required for a Rowland or Abney mounting. It can therefore be used in smaller laboratories and is less troubled by temperature gradients which are more likely to exist in the larger space. Furthermore, the compactness of the mounting makes it easy to secure great rigidity for it. The fact that the mounting in parallel light brings the spectrum closer to the grating results in reducing the dispersion to about half of what it would be in the Rowland mounting. The aperture ratio being doubled the intensity of the spectra is theoretically quadrupled. To be sure some light is lost by absorption in the auxiliary mirror, but this loss is probably more than compensated by the elimination of astigmatism. With the grating described above a 10-second exposure is ample for the iron arc spectrum at 3000 A, and only 15 minutes are required to photograph this spectrum at 9000 A. Our experience leads us to believe that the spectra from a grating in parallel light are effectively from 5 to 10 times as intense as when mounted according to Rowland.

IV. THE PREPARATION OF SPECTRUM TUBES

The spectroscopy section of this Bureau has for many years been making and testing glass tubes containing various gases and furnishing these to scientific institutions which require them for standard sources of monochromatic light to be used in optical testing and research. Tubes containing hydrogen, oxygen, nitrogen, helium, neon, and argon have been produced in considerable numbers, but the demand is always greater than the supply, and it is therefore thought advisable to give a few notes on our simple methods, so that institutions possessing a fairly good vacuum pump and a glass blower can prepare their own tubes.

Detailed instructions for the filling of Plücker tubes for the production of luminescence in gases were given in 1912 by Baly,[14]

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[14] Baly, Spectroscopy, Longmans, Green & Co., pp. 421–438; 1912.

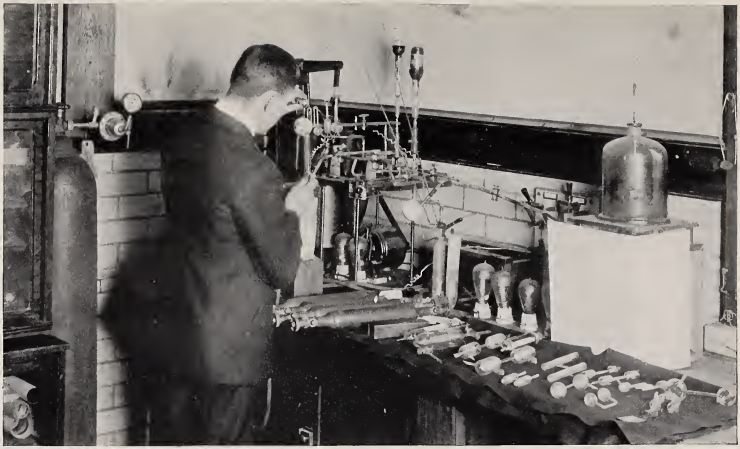

Fig. 6.—*Preparation of spectrum tubes, showing vacuum pump, tube filling apparatus, and various types of tubes, one of which (the grid tube) is being sealed off*

but certain features of the process have been simplified or require modification to accord with recent experience or with local laboratory facilities. The number of Plücker tube designs is very large, and a certain variety of special forms are essential for special purposes, but for all ordinary investigations and tests the simple form described in Bureau of Standards Bulletin, 4, page 511 (1907), has been found to be quite satisfactory.

The electrodes are aluminum disks of 25 mm diameter and 1 mm thickness, contained in spherical glass bulbs of 35 mm diameter, which are connected by a stem with 1 to 2 mm bore and 10 cm length. This form of electrode permits relatively large currents with a minimum of heating and evaporation and deposition. Convenient apparatus for filling such tubes with a low pressure of pure gas is illustrated in Fig. 6. Its principal feature is a good vacuum pump operating with oil. Pumps operating with mercury are not recommended, since there is always great danger of mercury vapor getting into the tube and contaminating or masking the spectrum of the gas. Laboratories equipped with mercury pumps may use these if a trap of liquid air, of gold foil, or of tin-cadmium alloy[15] is inserted between the pump and the remainder of the apparatus. Supplies of gases with which tubes are to be filled must also be kept from contamination with mercury. This is best accomplished by the method described in Bureau of Standards Bulletin, 4, page 512 (1907). To measure gaseous pressure in tubes, an oil manometer may be used.

The greatest care is necessary to secure a pure spectrum from a particular gas. Before filling the tubes they must be thoroughly exhausted, so that all traces of water vapor, occluded gases, hydrogen from the electrodes, carbon compounds from stopcock grease, etc., are withdrawn. Passage of strong electric current through the tube and external heating with a Bunsen flame during exhaustion is advisable. In this connection the advantages of using tubes made of Pyrex glass or of fused quartz are too obvious to require mention.

Tubes may be filled with hydrogen by attaching them to an electrolytic generator. An intense Balmer series is appropriate for many optical tests and, in the light of recent investigations, [16] can be best obtained with a very long tube containing hydrogen and a trace of water vapor.

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[15] Phys. Rev., **10**, p. 583; 1917.

[16] Wood, Phil. Mag., **42**, p. 729; 1921.

The spectrum of oxygen can be obtained from tubes connected with the negative branch of an electrolytic generator or with a small bulb or tube containing potassium chlorate ($KClO_3$) which may be heated to evolve a considerable quantity of O_2. Oxygen combines very readily with aluminum, so that such tubes soon become vacuous unless provision is made for frequent or continuous additions of the gas. Platinum electrodes are preferred in this case.

An evacuated tube filled with a small quantity of dry air will show the spectrum of nitrogen, becoming pure when the oxygen is absorbed by the electrodes, or the air may be passed first through hot copper turnings which abstract the oxygen.

The inert gases, helium, neon, and argon, give spectra which contain sharp lines suitable as standards of wave length, and the demand for these tubes is increasing among spectroscopists and metrologists. These gases are now readily obtainable commercially, although the heavier ones, krypton and xenon, are not. The helium family of gases is very favorable toward electrode sputtering, especially at low pressures of the gases. When the dark space surrounding the electrodes reaches the walls of the tube a bright metallic mirror is formed, and the gas is apparently adsorbed or trapped by the deposited metal, leaving the tube vacuous. If the initial pressure of the gas is relatively high (5 to 10 mm), the tubes give long and satisfactory service.

Helium may be obtained in the laboratory from the radioactive minerals, such as thorianite, cleveite, etc. For making tubes of helium we have found the new "balloon gas" serviceable. Large quantities of this gas [17] are readily available in a state of about 93 per cent pure helium, the remainder being principally nitrogen, which can be abstracted with hot metallic calcium or activated charcoal in liquid air.[18]. By filling a tube with a small quantity of the impure helium and passing a strong electric current through the tube we find that the impurities are absorbed by the electrodes and the spectrum of pure helium remains. Successive additions of small quantities of the impure gas and continuous passage of a strong current finally produce a tube containing pure helium at the desired pressure.

Before argon could be readily obtained commercially this Bureau made argon tubes by the following simple method, the details of which were developed by William H. Taylor. The Plücker tube is sealed to a tube of pyrex glass or fused silica containing metallic calcium in the form of turnings or filings, the combination being filled with air. By slowly heating the calcium to 600 ° C the active gases with the exception of hydrogen are removed in about an hour. The temperature of the calcium is then reduced to 250° C, and the hydrogen is absorbed in about one-half hour, after which the tube is sealed off. The argon is then at a pressure of about 8 mm, which gives a good spectrum. The traces of helium and the other rare atmospheric gases are insufficient to show spectra.

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[17] J. Frank. Inst., **191**, p. 145; 1921.

[18] Phys. Rev., **14**, p. 281; 1921.

The calcium container may be conveniently heated by means of a simple electric furnace, made by winding insulated wire around a brass tube and coating with water glass. If the calcium and the Plücker tubes are of different types of glass, the seal may be made with Khotinsky cement and the junction water cooled during the heating.

WASHINGTON, February 1, 1922.

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[illegible]